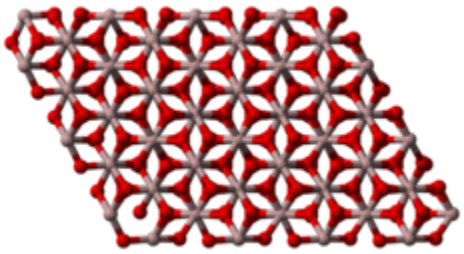
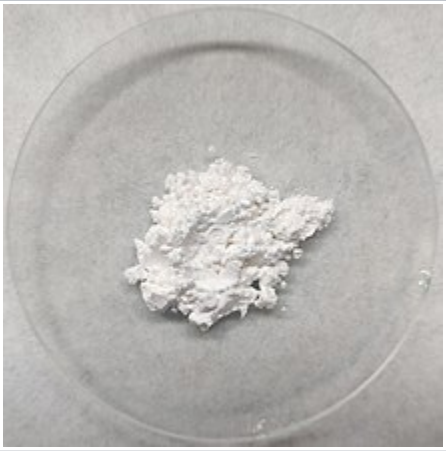
Aluminium oxide

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as **aluminium(III) oxide**. It is commonly called **alumina** and may also be called **aloxide**, **aloxite**, or **alundum** depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase α-Al_2O_3 as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.[7]

Aluminium oxide (Aluminum oxide)	
	
	
Identifiers	
CAS Number	1344-28-1 (https://commonchemistry.cas.org/detail?cas_rn=1344-28-1) ✓
3D model (JSmol)	Interactive image (https://chemapps.stolaf.edu/jmol/jmol.php?model=%5BAl%2B3%5D.%5BAl%2B3%5D.%5BO-2%5D.%5BO-2%5D.%5BO-2%5D) Interactive image (https://chemapps.stolaf.edu/jmol/jmol.php?model=%5BO-2%5D.%5BO-2%5D.%5BO-2%5D.%5BAl%2B3%5D.%5BAl%2B3%5D)
ChEMBL	ChEMBL3707210 (https://www.ebi.ac.uk/chembldb/index.php/compound/inspect/ChEMBL3707210)
ChemSpider	8164808 (https://www.chemspider.com/Chemical-Structure.8164808.html) ✓
DrugBank	DB11342 (https://www.drugbank.ca/drugs/DB11342)
ECHA InfoCard	100.014.265 (https://echa.europa.eu/substance-i

	~~nformation/-/substanceinfo/100.014.265)~~
EC Number	215-691-6
PubChem CID	9989226 (https://pubchem.ncbi.nlm.nih.gov/compound/9989226)
RTECS number	BD120000
UNII	LMI26O6933 (https://fdasis.nlm.nih.gov/srs/srsdirect.jsp?regno=LMI26O6933) ✓
CompTox Dashboard (EPA)	DTXSID1052791 (https://comptox.epa.gov/dashboard/chemical/details/DTXSID1052791)

InChI

InChI=1S/2Al.3O/q2*+3;3*-2 ✓
Key: PNEYBMLMFCGWSK-UHFFFAOYSA-N ✓

InChI=1/2Al.3O/q2*+3;3*-2
Key: PNEYBMLMFCGWSK-UHFFFAOYAC

SMILES

[Al+3].[Al+3].[O-2].[O-2].[O-2]

[O-2].[O-2].[O-2].[Al+3].[Al+3]

Properties

Chemical formula	Al_2O_3
Molar mass	101.960 g·mol^{-1}
Appearance	white solid
Odor	odorless
Density	3.987g/cm^3
Melting point	2,072 °C (3,762 °F; 2,345 K)[3]
Boiling point	2,977 °C (5,391 °F; 3,250 K)[4]
Solubility in water	insoluble
Solubility	insoluble in all solvents
log *P*	0.31860[1]
Magnetic susceptibility (χ)	−37.0×10^{-6} cm^3/mol

Thermal conductivity	30 $W \cdot m^{-1} \cdot K^{-1}$[2]
Refractive index (n_D)	n_ω=1.768–1.772 n_ε=1.760–1.763 Birefringence 0.008
Structure	
Crystal structure	Trigonal, hR30
Space group	$R\bar{3}c$ (No. 167)
Lattice constant	*a* = 478.5 pm, *c* = 1299.1 pm
Coordination geometry	octahedral
Thermochemistry	
Std molar entropy ($S^\ominus_{298}$)	50.92 $J \cdot mol^{-1} \cdot K^{-1}$[5]
Std enthalpy of formation ($\Delta_f H^\ominus_{298}$)	−1675.7 kJ/mol[5]
Pharmacology	
ATC code	D10AX04 (WHO (https://www.whocc.no/atc_ddd_index/?code=D10AX04))
Hazards	
GHS labelling:	
Pictograms	
NFPA 704 (fire diamond)	
Flash point	Non-flammable
NIOSH (US health exposure limits):	
PEL (Permissible)	OSHA 15 mg/m^3 (Total Dust) OSHA 5 mg/m^3 (Respirable Fraction)

	ACGIH/TLV 10 mg/m^3
REL (Recommended)	none[6]
IDLH (Immediate danger)	N.D.[6]
Related compounds	
Other anions	aluminium hydroxide aluminium sulfide aluminium selenide
Other cations	boron trioxide gallium oxide indium oxide thallium(III) oxide
Supplementary data page	
Aluminium oxide (data page)	
Except where otherwise noted, data are given for materials in their standard state (at 25 °C [77 °F], 100 kPa). ✓ verify (https://en.wikipedia.org/w/index.php?title=Special:ComparePages&rev1=477315085&page2=Aluminium+oxide) (what is ✓✗ ?) Infobox references	

Natural occurrence

Corundum is the most common naturally occurring crystalline form of aluminium oxide.[8] Rubies and sapphires are gem-quality forms of corundum, which owe their characteristic colours to trace impurities. Rubies are given their characteristic deep red colour and their laser qualities by traces of chromium. Sapphires come in different colours given by various other impurities, such as iron and titanium. An extremely rare, δ form, occurs as the mineral deltalumite.[9][10]

Properties

Aluminium oxide in its powdered form

Al_2O_3 is an electrical insulator but has a relatively high thermal conductivity (30 $Wm^{-1}K^{-1}$)[2] for a ceramic material. Aluminium oxide is insoluble in water. In its most commonly occurring crystalline form, called corundum or α-aluminium oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools.[7]

Aluminium oxide is responsible for the resistance of metallic aluminium to weathering. Metallic aluminium is very reactive with atmospheric oxygen, and a thin passivation layer of aluminium oxide (4 nm thickness) forms on any exposed aluminium surface in a matter of hundreds of picoseconds.[11] This layer protects the metal from further oxidation. The thickness and properties of this oxide layer can be enhanced using a process called anodising. A number of alloys, such as aluminium bronzes, exploit this property by including a proportion of aluminium in the alloy to enhance corrosion resistance. The aluminium oxide generated by anodising is typically amorphous, but discharge assisted oxidation processes such as plasma electrolytic oxidation result in a significant proportion of crystalline aluminium oxide in the coating, enhancing its hardness.

Aluminium oxide was taken off the United States Environmental Protection Agency's chemicals lists in 1988. Aluminium oxide is on the EPA's Toxics Release Inventory list if it is a fibrous form.[12]

Amphoteric nature

Aluminium oxide is an amphoteric substance, meaning it can react with both acids and bases, such as hydrofluoric acid and sodium hydroxide, acting as an acid with a base and a base with an acid, neutralising the other and producing a salt.

$Al_2O_3 + 6\ HF \rightarrow 2\ AlF_3 + 3\ H_2O$
$Al_2O_3 + 2\ NaOH + 3\ H_2O \rightarrow 2\ NaAl(OH)_4$ (sodium aluminate)

Structure

Corundum from Brazil, size about 2×3 cm.

The most common form of crystalline aluminium oxide is known as corundum, which is the thermodynamically stable form.[13] The oxygen ions form a nearly hexagonal close-packed structure with the aluminium ions filling two-thirds of the octahedral interstices. Each Al^{3+} center is octahedral. In terms of its crystallography, corundum adopts a trigonal Bravais lattice with a space group of $R\bar{3}c$ (number 167 in the International Tables). The primitive cell contains two formula units of aluminium oxide.

Aluminium oxide also exists in other metastable phases, including the cubic γ and η phases, the monoclinic θ phase, the hexagonal χ phase, the orthorhombic κ phase and the δ phase that can be tetragonal or orthorhombic.[13][14] Each has a unique crystal structure and properties. Cubic γ-Al_2O_3 has important technical applications. The so-called β-Al_2O_3 proved to be $NaAl_{11}O_{17}$.[15]

Molten aluminium oxide near the melting temperature is roughly 2/3 tetrahedral (i.e. 2/3 of the Al are surrounded by 4 oxygen neighbors), and 1/3 5-coordinated, with very little (<5%) octahedral Al-O present.[16] Around 80% of the oxygen atoms are shared among three or more Al-O polyhedra, and the majority of inter-polyhedral connections are corner-sharing, with the remaining 10–20% being edge-sharing.[16] The breakdown of octahedra upon melting is accompanied by a relatively large volume increase (~33%), the density of the liquid close to its melting point is 2.93 g/cm^3.[17] The structure of molten alumina is temperature dependent and the fraction of 5- and 6-fold aluminium increases during cooling (and supercooling), at the expense of tetrahedral AlO_4 units, approaching the local structural arrangements found in amorphous alumina.[18]

Production

Aluminium hydroxide minerals are the main component of bauxite, the principal ore of aluminium. A mixture of the minerals comprise bauxite ore, including gibbsite ($Al(OH)_3$), boehmite (γ-AlO(OH)), and diaspore (α-AlO(OH)), along with impurities of iron oxides and hydroxides, quartz and clay minerals.[19] Bauxites are found in laterites. Bauxite is typically purified using the Bayer process:

$$Al_2O_3 + H_2O + NaOH \rightarrow NaAl(OH)_4$$
$$Al(OH)_3 + NaOH \rightarrow NaAl(OH)_4$$

Except for SiO_2, the other components of bauxite do not dissolve in base. Upon filtering the basic mixture, Fe_2O_3 is removed. When the Bayer liquor is cooled, $Al(OH)_3$ precipitates, leaving the silicates in solution.

$$NaAl(OH)_4 \rightarrow NaOH + Al(OH)_3$$

The solid $Al(OH)_3$ Gibbsite is then calcined (heated to over 1100 °C) to give aluminium oxide:[7]

$$2\,Al(OH)_3 \rightarrow Al_2O_3 + 3\,H_2O$$

The product aluminium oxide tends to be multi-phase, i.e., consisting of several phases of aluminium oxide rather than solely corundum.[14] The production process can therefore be optimized to produce a tailored product. The type of phases present affects, for example, the solubility and pore structure of the aluminium oxide product which, in turn, affects the cost of aluminium production and pollution control.[14]

Applications

Known as alpha alumina in materials science communities or alundum (in fused form) or aloxite[20] in the mining and ceramic communities aluminium oxide finds wide use. Annual world production of aluminium oxide in 2015 was approximately 115 million tonnes, over 90% of which is used in the manufacture of aluminium metal.[7] The major uses of speciality aluminium oxides are in refractories, ceramics, polishing and abrasive applications. Large tonnages of aluminium hydroxide, from which alumina is derived, are used in the manufacture of zeolites, coating titania pigments, and as a fire retardant/smoke suppressant.

Over 90% of the aluminium oxide, normally termed Smelter Grade Alumina (SGA), produced is consumed for the production of aluminium, usually by the Hall–Héroult process. The remainder, normally called speciality alumina is used in a wide variety of applications which reflect its inertness, temperature resistance and electrical resistance.[21]

Fillers

Being fairly chemically inert and white, aluminium oxide is a favored filler for plastics. Aluminium oxide is a common ingredient in sunscreen and is sometimes also present in cosmetics such as blush, lipstick, and nail polish.

Glass

Many formulations of glass have aluminium oxide as an ingredient.[22] Aluminosilicate glass is a commonly used type of glass that often contains 5% to 10% alumina.

Catalysis

Aluminium oxide catalyses a variety of reactions that are useful industrially. In its largest scale application, aluminium oxide is the catalyst in the Claus process for converting hydrogen sulfide waste gases into elemental sulfur in refineries. It is also useful for dehydration of alcohols to alkenes.

Aluminium oxide serves as a catalyst support for many industrial catalysts, such as those used in hydrodesulfurization and some Ziegler–Natta polymerizations.

Gas purification

Aluminium oxide is widely used to remove water from gas streams.[23]

Abrasive

Aluminium oxide is used for its hardness and strength. Its naturally occurring form, corundum, is a 9 on the Mohs scale of mineral hardness (just below diamond). It is widely used as an abrasive, including as a much less expensive substitute for industrial diamond. Many types of sandpaper use aluminium oxide crystals. In addition, its low heat retention and low specific heat make it widely used in grinding operations, particularly cutoff tools. As the powdery abrasive mineral aloxite, it is a major component, along with silica, of the cue tip "chalk" used in billiards. Aluminium oxide powder is used in some CD/DVD polishing and scratch-repair kits. Its polishing qualities are also behind its use in toothpaste. It is also used in microdermabrasion, both in the

machine process available through dermatologists and estheticians, and as a manual dermal abrasive used according to manufacturer directions.

Paint

Aluminium oxide flakes are used in paint for reflective decorative effects, such as in the automotive or cosmetic industries.

Composite fiber

Aluminium oxide has been used in a few experimental and commercial fiber materials for high-performance applications (e.g., Fiber FP, Nextel 610, Nextel 720).[24] Alumina nanofibers in particular have become a research field of interest.

Body armor

Some body armors utilize alumina ceramic plates, usually in combination with aramid or UHMWPE backing to achieve effectiveness against most rifle threats. Alumina ceramic armor is readily available to most civilians in jurisdictions where it is legal, but is not considered military grade.[25]

Abrasion protection

Aluminium oxide can be grown as a coating on aluminium by anodizing or by plasma electrolytic oxidation (see the "Properties" above). Both the hardness and abrasion-resistant characteristics of the coating originate from the high strength of aluminium oxide, yet the porous coating layer produced with conventional direct current anodizing procedures is within a 60–70 Rockwell hardness C range[26] which is comparable only to hardened carbon steel alloys, but considerably inferior to the hardness of natural and synthetic corundum. Instead, with plasma electrolytic oxidation, the coating is porous only on the surface oxide layer while the lower oxide layers are much more compact than with standard DC anodizing procedures and present a higher crystallinity due to the oxide layers being remelted and densified to obtain α-Al2O3 clusters with much higher coating hardness values circa 2000 Vickers hardness.

Aluminium oxide output in 2005

Alumina is used to manufacture tiles which are attached inside pulverized fuel lines and flue gas ducting on coal fired power stations to protect high wear areas. They are not suitable for areas with high impact forces as these tiles are brittle and susceptible to breakage.

Electrical insulation

Aluminium oxide is an electrical insulator used as a substrate (silicon on sapphire) for integrated circuits but also as a tunnel barrier for the fabrication of superconducting devices such as single-electron transistors and superconducting quantum interference devices (SQUIDs).

For its application as an electrical insulator in integrated circuits, where the conformal growth of a thin film is a prerequisite and the preferred growth mode is atomic layer deposition, Al_2O_3 films can be prepared by the chemical exchange between trimethylaluminum ($Al(CH_3)_3$) and H_2O:[27]

$$2\ Al(CH_3)_3 + 3\ H_2O \rightarrow Al_2O_3 + 6\ CH_4$$

H_2O in the above reaction can be replaced by ozone (O_3) as the active oxidant and the following reaction then takes place:[28][29]

$$2\ Al(CH_3)_3 + O_3 \rightarrow Al_2O_3 + 3\ C_2H_6$$

The Al_2O_3 films prepared using O_3 show 10–100 times lower leakage current density compared with those prepared by H_2O.

Aluminium oxide, being a dielectric with relatively large band gap, is used as an insulating barrier in capacitors.[30]

Other

In lighting, translucent aluminium oxide is used in some sodium vapor lamps.[31] Aluminium oxide is also used in preparation of coating suspensions in compact fluorescent lamps.

In chemistry laboratories, aluminium oxide is a medium for chromatography, available in basic (pH 9.5), acidic (pH 4.5 when in water) and neutral formulations.

Health and medical applications include it as a material in hip replacements[7] and birth control pills.[32]

It is used as a scintillator[33] and dosimeter for radiation protection and therapy applications for its optically stimulated luminescence properties.

Insulation for high-temperature furnaces is often manufactured from aluminium oxide. Sometimes the insulation has varying percentages of silica depending on the temperature rating of the material. The insulation can be made in blanket, board, brick and loose fiber forms for various application requirements.

Small pieces of aluminium oxide are often used as boiling chips in chemistry.

It is also used to make spark plug insulators.[34]

Using a plasma spray process and mixed with titania, it is coated onto the braking surface of some bicycle rims to provide abrasion and wear resistance.

Most ceramic eyes on fishing rods are circular rings made from aluminium oxide.

In its finest powdered (white) form, called Diamantine, aluminium oxide is used as a superior polishing abrasive in watchmaking and clockmaking.[35]

Aluminium oxide is also used in the coating of stanchions in the motorcross and mountainbike industry. This coating is combined with molybdenumdisulfate to provide long term lubrication of the surface.[36]

See also

- Aluminium oxide nanoparticle
- Bauxite tailings
- Beta-alumina solid electrolyte, a fast ion conductor
- Charged Aerosol Release Experiment (CARE)
- List of alumina refineries
- Micro-Pulling-Down

- Transparent alumina

References

1. "Aluminum oxide_msds" (https://www.chemsrc.com/en/cas/1344-28-1_177878.html) .
2. Material Properties Data: Alumina (Aluminum Oxide) (http://www.makeitfrom.com/data/?material=Alumina) Archived (https://web.archive.org/web/20100401131344/http://www.makeitfrom.com/data/?material=Alumina) 2010-04-01 at the Wayback Machine. Makeitfrom.com. Retrieved on 2013-04-17.
3. Patnaik, P. (2002). Handbook of Inorganic Chemicals. McGraw-Hill. ISBN 978-0-07-049439-8.
4. Raymond C. Rowe; Paul J. Sheskey; Marian E. Quinn (2009). "Adipic acid". Handbook of Pharmaceutical Excipients. Pharmaceutical Press. pp. 11–12. ISBN 978-0-85369-792-3.
5. Zumdahl, Steven S. (2009). Chemical Principles 6th Ed. Houghton Mifflin Company. ISBN 978-0-618-94690-7.
6. NIOSH Pocket Guide to Chemical Hazards. "#0021" (https://www.cdc.gov/niosh/npg/npgd0021.html) . National Institute for Occupational Safety and Health (NIOSH).
7. "Alumina (Aluminium Oxide) – The Different Types of Commercially Available Grades" (https://web.archive.org/web/20071010063029/http://www.azom.com/details.asp?ArticleID=1389) . The A to Z of Materials. 3 May 2002. Archived from the original (http://www.azom.com/details.asp?ArticleID=1389) on 10 October 2007. Retrieved 27 October 2007.
8. Elam, J. W. (October 2010). Atomic Layer Deposition Applications 6 (https://books.google.com/books?id=9WyXTae58DgC&q=Corundum+is+the+most+common+naturally+occurring+crystalline+form+of+aluminium+oxide.&pg=PA46) . The Electrochemical Society. ISBN 9781566778213.
9. "Deltalumite" (https://www.mindat.org/min-47933.html) .
10. "List of Minerals" (https://www.ima-mineralogy.org/Minlist.htm) . 21 March 2011.
11. Campbell, Timothy; Kalia, Rajiv; Nakano, Aiichiro; Vashishta, Priya; Ogata, Shuji; Rodgers, Stephen (1999). "Dynamics of Oxidation of Aluminium Nanoclusters using Variable Charge Molecular-Dynamics Simulations on Parallel Computers" (http://cacs.usc.edu/papers/Campbell-nAloxid-PRL99.pdf) (PDF). Physical Review Letters. **82** (24): 4866. Bibcode:1999PhRvL..82.4866C (https://ui.adsabs.harvard.edu/abs/1999PhRvL..82.4866C) . doi:10.1103/PhysRevLett.82.4866 (https://doi.org/10.1103%2FPhysRevLett.82.4866) . Archived (https://web.archive.org/web/20100701230226/http://cacs.usc.edu/papers/Campbell-nAloxid-PRL99.pdf) (PDF) from the original on 2010-07-01.
12. "EPCRA Section 313 Chemical List For Reporting Year 2006" (https://wayback.archive-it.org/all/20080522232533/http://www.epa.gov/tri/chemical/chemical%20lists/RY2006ChemicalList.pdf) (PDF). US EPA. Archived from the original (http://www.epa.gov/tri/chemical/chemical%20lists/RY2006ChemicalList.pdf) (PDF) on 2008-05-22. Retrieved 2008-09-30.

13. *I. Levin; D. Brandon (1999). "Metastable Alumina Polymorphs: Crystal Structures and Transition Sequences". Journal of the American Ceramic Society.* ***81*** *(8): 1995–2012. doi:10.1111/j.1151-2916.1998.tb02581.x (https://doi.org/10.1111%2Fj.1151-2916.1998.tb02581.x)* .

14. *Paglia, G. (2004). "Determination of the Structure of γ-Alumina using Empirical and First Principles Calculations Combined with Supporting Experiments" (http://espace.library.curtin.edu.au/R?func=search-simple-go&ADJACENT=Y&REQUEST=adt-WCU20040621.123301)* *(free download). Curtin University of Technology, Perth. Retrieved 2009-05-05.*

15. *Wiberg, E.; Holleman, A. F. (2001). Inorganic Chemistry. Elsevier. ISBN 978-0-12-352651-9.*

16. *Skinner, L.B.; et al. (2013). "Joint diffraction and modeling approach to the structure of liquid alumina" (https://doi.org/10.1103%2FPhysRevB.87.024201)* *. Phys. Rev. B.* ***87*** *(2): 024201. Bibcode:2013PhRvB..87b4201S (https://ui.adsabs.harvard.edu/abs/2013PhRvB..87b4201S)* *. doi:10.1103/PhysRevB.87.024201 (https://doi.org/10.1103%2FPhysRevB.87.024201)* .

17. *Paradis, P.-F.; et al. (2004). "Non-Contact Thermophysical Property Measurements of Liquid and Undercooled Alumina". Jpn. J. Appl. Phys.* ***43*** *(4): 1496–1500. Bibcode:2004JaJAP..43.1496P (https://ui.adsabs.harvard.edu/abs/2004JaJAP..43.1496P)* *. doi:10.1143/JJAP.43.1496 (https://doi.org/10.1143%2FJJAP.43.1496)* *. S2CID 250779901 (https://api.semanticscholar.org/CorpusID:250779901)* .

18. *Shi, C; Alderman, O L G; Berman, D; Du, J; Neuefeind, J; Tamalonis, A; Weber, R; You, J; Benmore, C J (2019). "The structure of amorphous and deeply supercooled liquid alumina" (https://doi.org/10.3389%2Ffmats.2019.00038)* *. Frontiers in Materials.* ***6*** *(38): 38. Bibcode:2019FrMat...6...38S (https://ui.adsabs.harvard.edu/abs/2019FrMat...6...38S)* *. doi:10.3389/fmats.2019.00038 (https://doi.org/10.3389%2Ffmats.2019.00038)* .

19. *"Bauxite and Alumina Statistics and Information" (http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/)* *. USGS. Archived (https://web.archive.org/web/20090506220703/http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/)* *from the original on 6 May 2009. Retrieved 2009-05-05.*

20. *"Aloxite" (http://www.chemindustry.com/chemicals/14835.html)* *. ChemIndustry.com database. Archived (https://web.archive.org/web/20070625100844/http://www.chemindustry.com/chemicals/14835.html)* *from the original on 25 June 2007. Retrieved 24 February 2007.*

21. *Evans, K. A. (1993). "Properties and uses of aluminium oxides and aluminium hydroxides". In Downs, A. J. (ed.). The Chemistry of Aluminium, Indium and Gallium. Blackie Academic. ISBN 978-0751401035.*

22. *Akers, Michael J. (2016-04-19). Sterile Drug Products: Formulation, Packaging, Manufacturing and Quality (https://books.google.com/books?id=C2_LBQAAQBAJ&q=some+glass+contain+aluminum+oxide&pg=PA73)* *. CRC Press. ISBN 9781420020564.*

23. *Hudson, L. Keith; Misra, Chanakya; Perrotta, Anthony J.; Wefers, Karl and Williams, F. S. (2002) "Aluminum Oxide" in Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH, Weinheim. doi:10.1002/14356007.a01_557 (https://doi.org/10.1002%2F14356007.a01_557)* .

24. *Mallick, P.K. (2008). Fiber-reinforced composites materials, manufacturing, and design (3rd ed., [expanded and rev. ed.] ed.). Boca Raton, FL: CRC Press. pp. Ch.2.1.7. ISBN 978-0-8493-4205-9.*

25. *"Ballistic Resistance of Body Armor" (https://www.ncjrs.gov/pdffiles1/nij/223054.pdf) (PDF). US Department of Justice. NIJ. Retrieved 31 August 2018.*

26. *Osborn, Joseph H. (2014). "understanding and specifying anodizing: what a manufacturer needs to know" (https://web.archive.org/web/20161120010024/http://www.omwcorp.com/understandingano/anoindex.html) . OMW Corporation. Archived from the original (http://www.omwcorp.com/understandingano/anoindex.html) on 2016-11-20. Retrieved 2018-06-02.*

27. *Higashi GS, Fleming (1989). "Sequential surface chemical reaction limited growth of high quality Al_2O_3 dielectrics". Appl. Phys. Lett. **55** (19): 1963–65. Bibcode:1989ApPhL..55.1963H (https://ui.adsabs.harvard.edu/abs/1989ApPhL..55.1963H) . doi:10.1063/1.102337 (https://doi.org/10.1063%2F1.102337) .*

28. *Kim JB; Kwon DR; Chakrabarti K; Lee Chongmu; Oh KY; Lee JH (2002). "Improvement in Al_2O_3 dielectric behavior by using ozone as an oxidant for the atomic layer deposition technique". J. Appl. Phys. **92** (11): 6739–42. Bibcode:2002JAP....92.6739K (https://ui.adsabs.harvard.edu/abs/2002JAP....92.6739K) . doi:10.1063/1.1515951 (https://doi.org/10.1063%2F1.1515951) .*

29. *Kim, Jaebum; Chakrabarti, Kuntal; Lee, Jinho; Oh, Ki-Young; Lee, Chongmu (2003). "Effects of ozone as an oxygen source on the properties of the Al_2O_3 thin films prepared by atomic layer deposition". Mater Chem Phys. **78** (3): 733–38. doi:10.1016/S0254-0584(02)00375-9 (https://doi.org/10.1016%2FS0254-0584%2802%2900375-9) .*

30. *Belkin, A.; Bezryadin, A.; Hendren, L.; Hubler, A. (20 April 2017). "Recovery of Alumina Nanocapacitors after High Voltage Breakdown" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5430567) . Scientific Reports. **7** (1): 932. Bibcode:2017NatSR...7..932B (https://ui.adsabs.harvard.edu/abs/2017NatSR...7..932B) . doi:10.1038/s41598-017-01007-9 (https://doi.org/10.1038%2Fs41598-017-01007-9) . PMC 5430567 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5430567) . PMID 28428625 (https://pubmed.ncbi.nlm.nih.gov/28428625) .*

31. *"GE Innovation Timeline 1957–1970" (http://www.ge.com/innovation/timeline/eras/science_and_research.html) . Archived (https://web.archive.org/web/20090216233917/http://www.ge.com/innovation/timeline/eras/science_and_research.html) from the original on 16 February 2009. Retrieved 2009-01-12.*

32. *"DailyMed - JUNEL FE 1/20- norethindrone acetate and ethinyl estradiol, and ferrous fumarate" (https://dailymed.nlm.nih.gov/dailymed/drugInfo.cfm?setid=75bb0024-8f1a-4036-9acd-006ea430f3b7#) . dailymed.nlm.nih.gov. Archived (https://web.archive.org/web/20170313130132/https://dailymed.nlm.nih.gov/dailymed/drugInfo.cfm?setid=75bb0024-8f1a-4036-9acd-006ea430f3b7) from the original on 2017-03-13. Retrieved 2017-03-13.*

33. *V.B. Mikhailik, H. Kraus (2005). "Low-temperature spectroscopic and scintillation characterisation of Ti-doped Al_2O_3". Nucl. Instr. Phys. Res. A. **546** (3): 523–534. Bibcode:2005NIMPA.546..523M (https://ui.adsabs.harvard.edu/abs/2005NIMPA.546..523M) . doi:10.1016/j.nima.2005.02.033 (https://doi.org/10.1016%2Fj.nima.2005.02.033) .*

34. *Farndon, John (2001). Aluminum (https://archive.org/details/aluminumtheeleme00john) . Marshall Cavendish. p. 19 (https://archive.org/details/aluminumtheeleme00john/page/19) . ISBN 9780761409472. "Aluminum oxide is also used to make spark plug insulators."*

35. *de Carle, Donald (1969). Practical Watch Repair. N.A.G. Press Ltd. p. 164. ISBN 0719800307.*

36. *"Kashima Coat - Products / Services | Next-generation anodize boasting light weight, high lubrication, and superb wear resistance. The answer is Miyaki's Kashima Coat" (http://www.kashima-coat.com/global/service/kashima-coat/) .*

External links

Wikimedia Commons has media related to ***Aluminium oxide***.

- CDC - NIOSH Pocket Guide to Chemical Hazards (https://www.cdc.gov/niosh/npg/npgd0021.html)

Last edited 1 month ago by Citation bot

WikipediA